Astronomy & Astrophysics manuscript no. 8977
February 2, 2008

SUMER-Hinode observations of microflares: excitation of molecular hydrogen

D. E. Innes

Max-Planck Institut für Sonnensystemforschung, 37191 Katlenburg-Lindau, Germany
e-mail: innes@mps.mpg.de

Received —-; accepted —-

ABSTRACT

Context. Concentrations of H_2 have been detected by SUMER in active region plage. The H_2 is excited by O VI line emission at 1031.94 Å which, although not observed, must be brightening along with the observed transition region line, Si III 1113.24 Å.
Aims. We investigate the excitation of H_2 and demonstrate the association between the observed H_2 emission and footpoints of X-ray microflares.
Methods. We have made co-ordinated observations of active region plage with the spectrometer SUMER/SoHO in lines of H_2 1119.10 Å and Si III 1113.24 Å and with XRT/Hinode X-ray and SOT/Hinode Ca II filters.
Results. In six hours of observation, six of the seven H_2 events seen occurred near a footpoint of a brightening X-ray loop. The seventh is associated with an unusually strong Si III plasma outflow.
Conclusions. Microflare energy dissipation heats the chromosphere, reducing its opacity, so that O VI microflare emission is able to reach the lower layers of the chromosphere and excite the H_2.

Key words. molecular processes – Sun: activity – Sun: flares – Sun: UV radiation

1. Introduction

Solar H_2 emission is strong in ultraviolet spectra of sunspots and has also been seen in flares (Bartoe et al. 1979). In the quiet Sun it is present but extremely weak (Sandlin et al. 1986). Here we report the first observations of H_2 concentrations in bright active region plage. The observed H_2 line at 1119.10 Å is the $1-3$ transition in the Werner series, excited by O VI 1032 Å (Bartoe et al. 1979; Schühle et al. 1999):

$$\mathrm{H_2}(v'' = 1, \mathrm{X}^1\Sigma_g^+) + h\nu(\mathrm{O\ VI}) \longrightarrow \mathrm{H_2}(v' = 1, \mathrm{C}^1\Pi_u) \longrightarrow$$
$$\longrightarrow \mathrm{H_2}(v'' = 3, \mathrm{X}^1\Sigma_g^+).$$

The 1119.10 Å line is about 60 % as bright as the strongest $1-4$ Werner line at 1164 Å. The H_2 is believed to be formed just above the temperature minimum at around 4200 K. Its strength is expected to correlate with the O VI intensity, as well as with the chromosphere structure in and above the H_2 region (Jordan et al. 1978).

In this letter, three types of H_2 plage events are discussed. The strongest coincided with ribbon-like Ca II chromospheric brightening at a footpoint of an X-ray microflare. The second occurred near the footpoint of a brightening X-ray loop with no signature in Ca II, and the third had neither X-ray emission nor a Ca II signature but very strong transition region outflow. All three events highlighted here occurred in three hours on one of the observing days. During the second day of observation, three H_2 events were detected in three hours, and all were associated with X-ray loop brightening with no Ca II signature.

Send offprint requests to: D. E. Innes

2. Observations

Hinode (Kosugi et al. 2007) and SUMER (Wilhelm et al. 1995) observed a small active region (AR 10953) on 29 and 30 Apr 2007. The region had produced several B and one C class flare four days earlier. All events during the observing period discussed here were below B class. On each day, SUMER made six rasters across the plage and sunspot. Each raster took 30 min. The lines observed were H_2 1119.10 Å (4.2×10^3 K), C I multiplet at 1114.39 Å and 1118.41 Å (10^4 K), Si III 1113.24 Å (6×10^4 K), and Ca X 2x557 Å (7×10^5 K), where the approximate formation temperatures of the lines are given in brackets. The spectrum across the sunspot is shown in Fig. 1. The sunspot is seen predominantly in the H_2 line.

Hinode made simultaneous observations with the X-Ray Telescope (XRT; Golub et al. 2007) through both the Ti-poly and Al-thick filters with 1.5 min cadence. Observations through both the Ca II and G-band filters were made with the Broadband Filter Imager of the Solar Optical Telescope (SOT; Tsuneta et al. 2007) with a 1 min cadence. The Extreme ultraviolet Imaging Spectrometer (EIS; Culhane et al. 2007) observed Fe XV 284.25 Å (2×10^6 K), using the wide 266″ slit and 15 s cadence. To obtain the coalignment between the X-ray images and SUMER, the EIS images were very useful because they bridged the gap between SOT Ca II and XRT. In particular, during the strongest microflare event, EIS captured both the X-ray loop seen with XRT and the ribbon-like footpoint structure seen in the SOT Ca II images. This provided the SOT, XRT, and EIS coalignment. The SUMER-SOT coalignment was made by comparing SOT G-band and SUMER H_2 images. Additional checks were done by comparing SUMER Si III and EIS Fe XV. The coalignment between SUMER and XRT is believed to be better than 5″, with greater accuracy in the north-south (sun-y) direction.

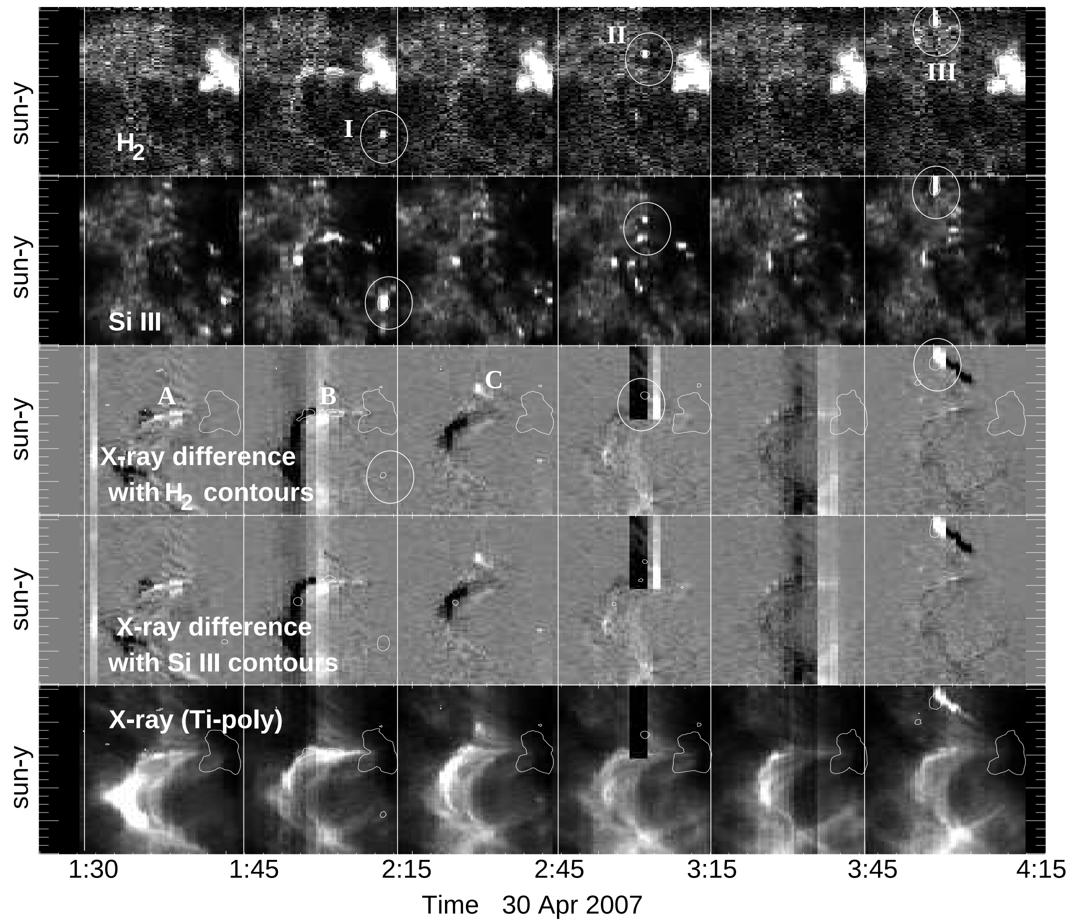

Fig. 2. The six raster scans taken in H_2 and Si III, and the equivalent X-ray time-slice rasters. The X-ray rasters are constructed by stacking, for each SUMER observation, the cospatial XRT slices from the XRT Ti-poly images closest in time. The difference images are computed by subtracting the preceding XRT Ti-poly image. The plage H_2 brightenings (labelled I, II, III) are circled in the H_2, Si III, and top X-ray difference raster. The H_2 contours are at 8×10^{-3} photons s^{-1} m^{-2} sr^{-1}, and Si III contours are at 1.2 photons s^{-1} m^{-2} sr^{-1}. All images have a linear intensity scale. The sun-x and sun-y co-ordinates are as in Fig. 3

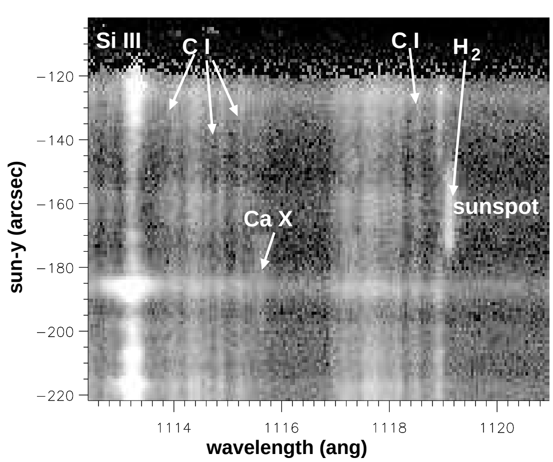

Fig. 1. SUMER spectrum of the region across and around the sunspot, taken on 29 Apr 2007 at 02:25 UT.

The six rasters taken on 30 Apr 2007 are shown as a time series in Fig. 2. Here, the sunspot is the bright H_2 region on the right of each raster. The linear intensity scale used to display the images accentuates the few plage brightenings, both in the H_2 and the Si III images. The three brightest H_2 concentrations are circled and labelled I, II, III. Each H_2 concentration coincides with intense Si III, but the inverse is not true. Not all Si III brightenings are associated with H_2. The relationship between the H_2 and X-ray brightenings is shown in the third row of Fig. 2. The two strongest H_2 events, II and III, are associated with X-ray brightenings. Unfortunately, the X-ray brightening at II is exaggerated by a data gap. Its brightening is seen better in the XRT difference images displayed in Fig. 3. Event III was much the brightest X-ray event during the observing period. This is the event, mentioned previously, that coincided with a small, bright ribbon-like structure seen in Ca II images. Close inspection of the X-ray difference rasters reveals additional X-ray brightenings, labelled A, B, and C in the third row of Fig. 2. Event B is associated with weak H_2 and Si III, and A and C only with weak Si III.

The SUMER spectra of the circled events (I, II, and III) are shown in Fig. 4. There is no simple relationship between the Si III strength and the H_2. In each case the H_2 strength is 1 – 1.5 DN, whereas the Si III varies by a factor of three. It is noticeable that the Si III emission is generally broader. In event II, it is offset by $2''$ from the H_2.

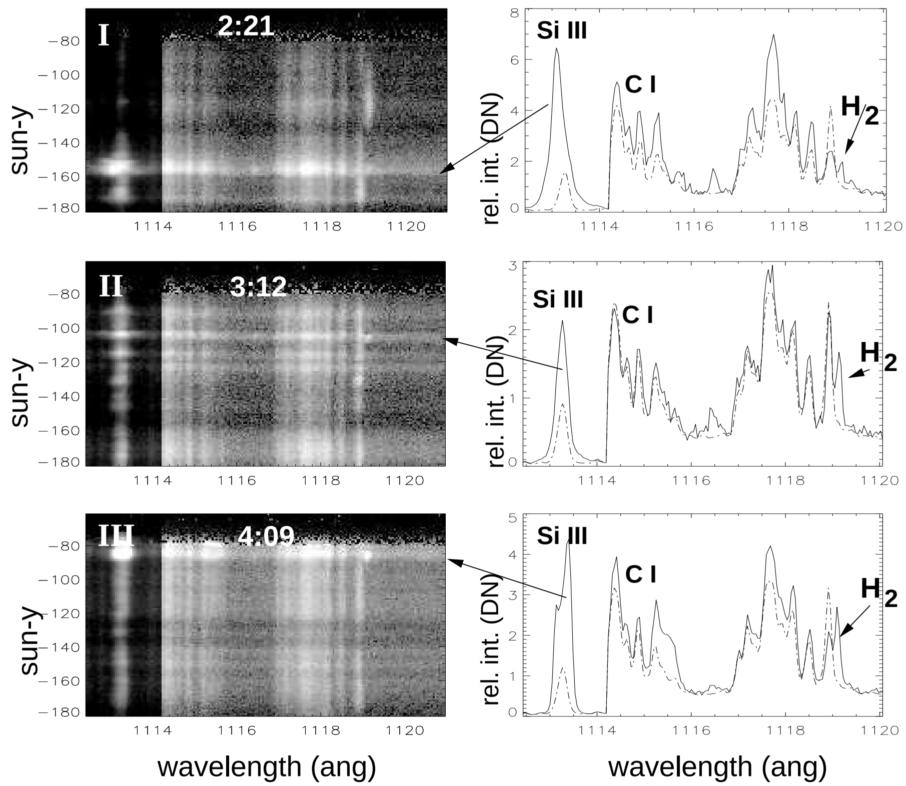

Fig. 4. SUMER spectral images and profiles of the H_2 brightenings. The Si III intensity is reduced by a factor 20 compared to the rest of the spectrum, so that they can be displayed with the same scale. Each H_2 spectrum is compared to the average plage spectrum, which has been scaled so that their continua at 1116 Å match.

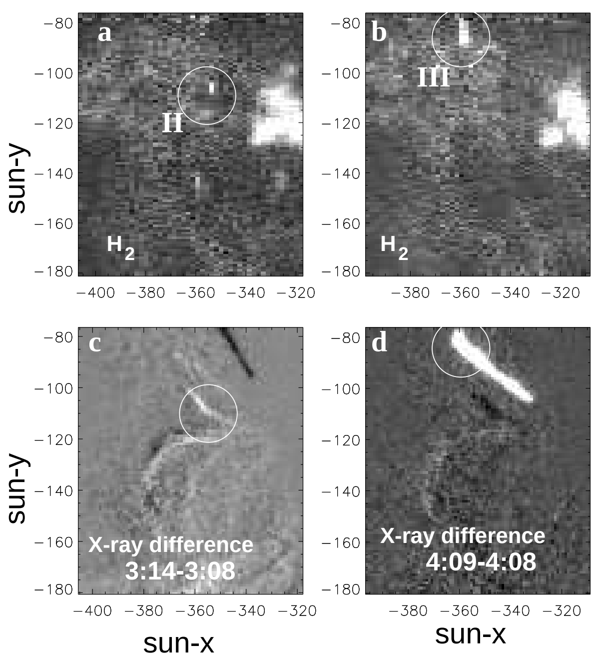

Fig. 3. SUMER raster images of H_2 (top row) and, below, the XRT Ti-poly difference images at the time of the H_2 brightenings.

3. Discussion

The H_2 intensity depends on both the strength of the O VI and the atmospheric opacity between the O VI and H_2 layers. If the O VI follows the Si III brightness, then an increase in transition region emission cannot be the only reason for enhanced H_2 excitation, because there are several examples of bright Si III and no observed H_2. The analyses by Jordan et al. (1978) and Bartoe et al. (1979) of H_2 in a sunspot and quiet Sun led them to conclude that the opacity over the sunspot is about an order of magnitude less than in the quiet Sun. This suggests a similar explanation for the H_2 concentrations in bright plage because energy dissipation at X-ray loop footpoints is commonly associated with chromospheric evaporation, and the two strongest events discussed here and all three events seen on 29 April 2007 were associated with X-ray loop brightening. The one event not associated with X-ray brightening showed significant plasma outflow from the transition region.

If chromospheric evaporation due to high-energy particles accelerated in the microflare reduces the opacity of the chromosphere, one might expect to find a relationship between the X-ray emission and the H_2. This is not confirmed by the observations presented here, but this could be because the observed H_2 strength depends critically on the position of the loop footpoint in relation to the SUMER field-of-view at the time of the brightening. The reason more Si III and X-ray coincidences occur is probably because Si III brightenings come from higher up in the atmosphere and cover a larger area, and not just from the loop footpoint.

Future observations with SUMER will measure the O VI 1032 Å and H_2 intensities almost simultaneously. This, together with extended SOT observations and analysis of the chromospheric dynamics, will help determine the extent and influence of opacity changes on the H_2 intensity.

Acknowledgements. I would like to thank Maria Madjarska for her constructive comments and careful reading of this letter. Hinode is a Japanese mission developed and launched by ISAS/JAXA, collaborating with NAOJ, as domestic partner, and NASA (USA) and STFC (UK) as international partners. Scientific operation of the Hinode mission is conducted by the Hinode science team organized at ISAS/JAXA. Support for the postlaunch operation is provided by JAXA and NAOJ, STFC, NASA, ESA (European Space Agency), and NSC (Norway). SUMER is financially supported by DLR, CNES, NASA, and the ESA PRODEX program (Swiss contribution). SoHO is a project of international co-operation between ESA and NASA. We are grateful to all teams for their efforts in the design, building, and operation of the Hinode and SoHO missions.

References

Bartoe, J.-D. F., Brueckner, G. E., Nicolas, K. R., et al. 1979, MNRAS, 187, 463
Culhane, J. L., Harra, L. K., James, A. M., et al. 2007, Sol. Phys., 60
Golub, L., Deluca, E., Austin, G., et al. 2007, Sol. Phys., 243, 63
Jordan, C., Brueckner, G. E., Bartoe, J.-D. F., Sandlin, G. D., & Vanhoosier, M. E. 1978, ApJ, 226, 687
Kosugi, T., Matsuzaki, K., Sakao, T., et al. 2007, Sol. Phys., 118
Sandlin, G. D., Bartoe, J.-D. F., Brueckner, G. E., Tousey, R., & Vanhoosier, M. E. 1986, ApJS, 61, 801
Schühle, U., Brown, C. M., Curdt, W., & Feldman, U. 1999, in ESA Special Publication, Vol. 446, 8th SOHO Workshop: Plasma Dynamics and Diagnostics in the Solar Transition Region and Corona, ed. J.-C. Vial & B. Kaldeich-Schü, 617
Tsuneta, S., Ichimoto, K., Katsukawa, Y., et al. 2007, ArXiv e-prints, 711.1715
Wilhelm, K., Curdt, W., Marsch, E., et al. 1995, Sol. Phys., 162, 189